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ORIGINAL PAPER

Intra- and inter-clonal tree growth variations of *Hevea brasiliensis*

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Abstract: We evaluated the effects of planting densities (500, 1,000, 1,500 and 2,000 trees·ha^{-1}) on tree growth performance (diameter at base, diameter at breast height, and clear bole height) of two clones (RRIM 2020 and RRIM 2025) of nine years old plantations of rubber tree (*Hevea brasiliensis* Muell. Arg) in Malaysia. For the four planting densities of the two clones, basal area and diameter at breast height declined with increasing planting density. Clear bole heights were greatest at 1,500 trees·ha^{-1}and lowest at 500 trees·ha^{-1} for the clone RRIM 2020, and at 2,000 trees·ha^{-1}and 500 trees·ha^{-1}for clone RRIM 2025. We conclude that the ideal planting density is 2,000 trees·ha^{-1} for obtaining high volume of wood production and 500 trees·ha^{-1} for high wood quality.

Key words: clone; planting density; tree growth; *Hevea brasiliensis*

Introduction

Fast growing and high yielding species are important sources of wood in the tropics (Pérez Corderoa et al. 2003). The role of forest plantation in meeting future wood and fiber demands will increase in the near-term, irrespective of rates of forest plantation establishment (Brown 2000; Alfred 2007).

Rubber tree (*Hevea brasiliensis*) is indigenous to the Amazon forests of Brazil and is one of the most important species for afforestation in the tropics. Mature trees in native habitat are about 25–30 m tall with an average diameter at breast height (DBH) >1 m. Early research to identify potential uses of rubber wood was initiated at the Forest Research Institute (FRI) in 1953 (IRRDB 2008). Now, rubberwood is widely planted for the production of timber (Tuberman 2007).

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Rubberwood is a light hardwood with an average air-dry density 640 kg·m^{-3}. The wood is whitish yellow and seasoned to light straw or light brown in color. The sapwood is generally not distinguishable from the heartwood. The wood texture is fairly even and fine, with moderately straight grain (Mohd Izham 2001). Rubberwood, like most tropical trees, does not show clear growth rings (Ogata et al. 2001; Nobuchi & Sahri 2008). In Malaysia, rubberwood increased from 26% of total exported wood products in 1998 to 35% in 2007 (Shigematsu et al. 2011).

Planting density is considered as an important factor affecting individual tree growth performance (Wei et al. 2005; Hein et al. 2008). Understanding the effects of planting density on individual tree features is an important step towards refinement in predicting the response of future silvicultural activities and increasing the value and utilization of forest products from plantation forests (Ballard & Long 1988; Zhu et al. 2007; Hein et al. 2008). One of the most important reasons to study the competition between trees is to understand their growth and development. Space plays an important role in optimum forest development. The size and spatial distribution of the canopy are effectively related to the quantity of light captured by the leaves. This relationship is used to measure the productivity in plantations in connection with the proportion of light energy converted into plant biomass. Hence, it is important to study planting densities to develop optimal tree growth and utilize a site for maximum production of wood biomass (Pérez Corderoa et al. 2003).

There are significant differences in above-ground biomass among different planting densities (Fangs et al. 2004). A six-year-long study showed the effect of planting density on *Eucalyptus camaldulensis* growth. Tree size was larger at lower planting density. Per acre volume and weight yields were greater at the higher planting density, while individual tree diameter, volume, and weight were greater at low planting density (Cockerham 2004). Stem growth is related to crown development. Crown structure is influenced by resource acquisition e.g. light quantity, nutrients, and water utilization (Grote & Pretzsch 2002).

Effective stand management involves controlling the spacing of the growing stock. Controlling stand density by varying planting density and thinning intensity has been the major tool in regulating tree growth and wood quality (Kenk 1990). Low stand

densities may, however, have reverse influence on timber quality. Previous studies have repeatedly shown that a rapid growth rate, particularly during the initial phases of stand development, results in thick branches and more excessive stem taper (Niemisto 1995; Pretzsch 2005). Information from low density to high density stands is required for clarifying the relationship between stand density, tree growth, and wood quality (Pérez Corderoa et al. 2003).

This research was carried out on *H. brasiliensis* plantations in Malaysia with the aim of developing the indicators of competition within a stand, such as diameter at base, diameter at breast height and clear bole height (height until the first living branch). The main objective of this study was to improve intensive management strategies for *H. brasiliensis* plantations to ensure high yields of timber.

Materials and methods

Study site and sample selection

Two trial clones, namely RRIM 2020 (clone I) and RRIM 2025 (clone II) at age of 9 years were selected for this study. The study site was located in RRIMINIS (Mini station of Rubber Research Institute of Malaysia) plots in Terengganu, Malaysia (Fig. 1). The plantation was located at latitude 5°45' N and longitude 102°30' E. The average precipitation during last three years was about 3,752 mm (Anonymous 2010).

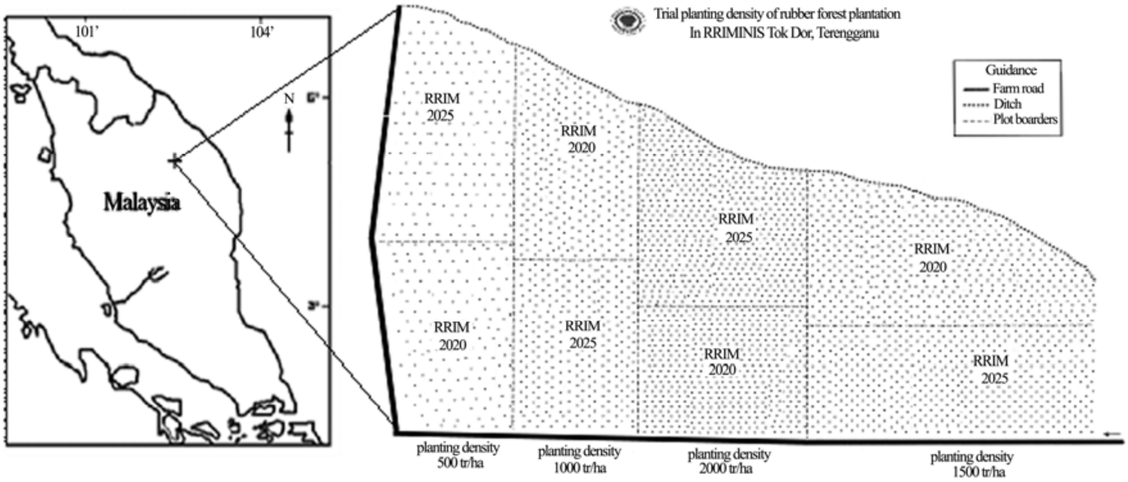

Fig. 1 Location of the study site

The planting densities (PD) in each clone were 500 (4.0 × 5.0 m, PD I), 1,000 (4.0 × 2.5 m, PD II), 1,500 (3.0 × 2.2 m, PD III) and 2,000 (2.0 × 2.5 m, PD IV) trees per hectare (trees·ha^{-1}). The trials were laid out in a randomized complete block design. The density trials were established to highlight the significance of spacing on tree growth and yield in year 2000. The main criterion in these plots was planting density. Nearly one hectare of sampling area was allocated to each planting density. Sampled trees were obtained from uniform stands and trees growing adjacent to the roadside, big gaps or leaning trees were avoided. All sampled trees had fairly straight boles and grew on the relatively uniform terrain. The trees were randomly selected.

The sampling plots were geographically located near to each other, so the environmental conditions were considered equal. The diameter at base (DB), diameter at breast height (DBH), and clear bole height of 30 trees from each planting density were measured (total 240 trees). Naturally, rubber trees grow taller than most other economical fast-growing species and measurement of tree height under intensive planting densities is very difficult. Therefore, we ignored height measurement (Rodrigo et al. 2004).

DB and DBH were measured using a diameter tape and clear bole height was measured using a fiberglass measuring rod. All measurements were done at nearly noon to minimize the errors caused by shrinkage of the stems. The data were analyzed using analysis of variance (ANOVA) and independent-sample T-test for comparison of means between and among the clones. The comparisons were performed using the Statistical Package for Social Science (PASW statistics processor, version 18) and the graphs were drawn with Microsoft Excel for Windows. The equation presumes every single tree as a cylinder shape from ground level to breast height (Cockerham 2004). The whole tree volume (A) was calculated based on a common tree volume equation (Zobeiry 2005). As stated earlier, the measuring height of tree in intensive plantation is very difficult, therefore the height of clear bole was used in tree volume calculation.

$$V = A \times \mu \times \alpha \tag{1}$$

where, $A = 0.4 \times d^2 \times h$, A is the volume estimation of a standing tree (m^3), d is the diameter at breast height (m), h is the height of clear bole (m), μ is mean of the plantation population (number of

trees per surface unit), and α is 80%, coefficient of living tree per hectare (coefficient of mortality)

Results

Effect of planting density on diameter at base (DB)

Planting density had significant influence on the DB of *H. brasiliensis*. The DB decreased with increasing planting density, which showed a direct correlation with planting distance. Maximum values of DB (27.99 cm and 24.62 cm) were recorded in PD I for both clones and minimum DB values (23.28 cm and 19.31 cm) were recorded in PD III (Table 1 and Fig. 2).

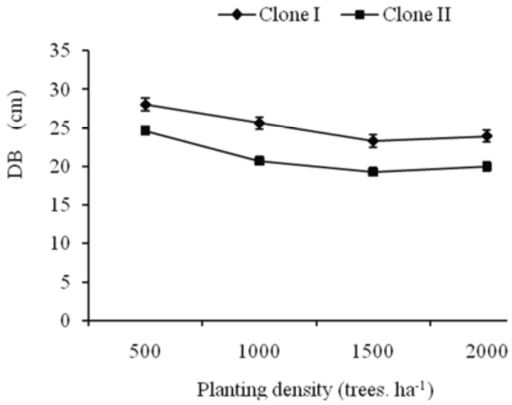

Fig. 2 Effect of planting density on DB in two clones and four planting densities at each clone of *H. brasiliensis*

Statistical comparison of mean DB among the same planting densities of the two clones revealed significant differences (Table 2).

Table 1. Average diameter at base (DB), diameter at breast height (DBH), and clear bole height (BH) in two clones and four planting densities of each clone.

Clone	Planting density	DB Mean (cm)	DB SD*	DBH Mean (cm)	DBH SD	Bole Height Mean (cm)	Bole Height SD
I	I	27.99^{a}	4.56	20.22^{a}	3.88	467^{a}	107.08
	II	25.60$^{a, b}$	4.26	19.19$^{a, b}$	3.20	863^{b}	99.82
	III	23.28^{b}	4.62	17.43^{b}	3.74	1023^{c}	130.43
	IV	23.92^{b}	4.31	17.54^{b}	3.91	936^{b}	110.38
II	I	24.62^{a}	2.81	19.96^{a}	2.29	738^{a}	120.87
	II	20.74^{b}	2.65	16.29^{b}	2.28	788^{a}	77.46
	III	19.31^{b}	2.94	15.27^{b}	2.36	909^{b}	98.09
	IV	19.98^{b}	3.35	15.07^{b}	2.38	1026^{c}	106.61

Means within columns with the same letter are not significantly different (p<0.05). The mean difference is significant at the 0.05 level. *Standard deviation

Effect of planting density on Diameter at Breast Height (DBH)

There was a negative relationship between DBH value and planting density (Fig. 3). As shown in Table 1, the mean DBH declined with increasing PD as: 20.22, 19.19, 17.43 and 17.54 cm for clone I and 19.96, 16.29, 15.27 and 15.07 cm for clone II in the four planting densities, respectively. Independent samples test verified the significant differences in growth performance between the same planting densities of the two clones except of PD I (Table 2).

Table 2. Independent *t*-test comparing the tree growth performances among the same planting densities of the two clones.

Growth performance	Planting density	t-test for equality of means: t	Sig.	S.E.*
DB	A_1-B_1	3.438	< 0.05	0.978
	A_2-B_2	5.316	< 0.05	0.916
	A_3-B_3	3.965	< 0.05	1.000
	A_4-B_4	3.960	< 0.05	0.997
DBH	A_1-B_1	0.312	**0.756**	0.822
	A_2-B_2	4.038	< 0.05	0.718
	A_3-B_3	2.675	< 0.05	0.807
	A_4-B_4	2.962	< 0.05	0.836
Bole Height	A_1-B_1	9.212	< 0.05	29.48
	A_2-B_2	3.225	< 0.05	23.07
	A_3-B_3	3.824	< 0.05	29.80
	A_4-B_4	3.215	< 0.05	27.98

Note: Bold type indicates no significant difference at the 0.05 probability level. *Standard error. $A_{(1,2,3,4)}$ and $B_{(1,2,3,4)}$ represents four different planting densities in clone I and clone II, respectively.

Effect of planting density on clear bole height

Mean bole height increased with increasing planting density (Fig. 4). Compared with the wider spacings (PD I and PD II), mean bole height in the closer spacings (PD III and PD IV) markedly increased as 467.17, 863.17, 1023.40, and 936.10 cm in clone I and 738.77, 788.77, 909.43, and 1026.10 cm in clone II, respectively. Mean bole height of the two clones at the same planting density showed significant differences (Table 2).

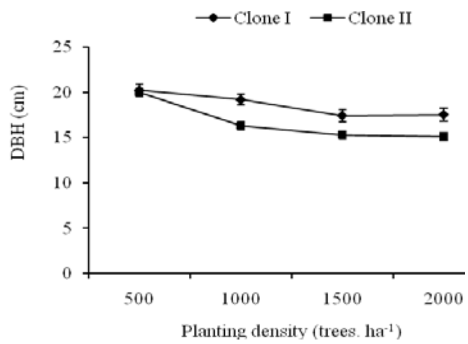

Fig. 3 Effect of planting density on DBH in two clones with four planting densities of *H. brasiliensis*

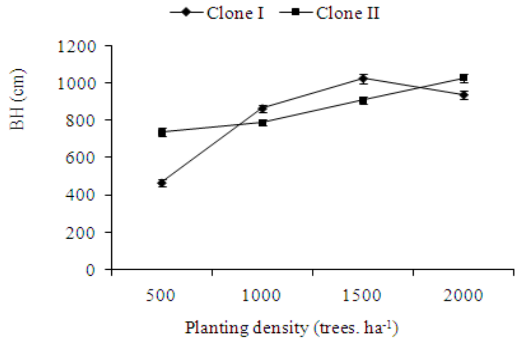

Fig. 4 Effect of planting density on clear bole height (BH) in two clones with four planting densities for each clone of *H. brasiliensis*

Total wood production per hectare for every planting density was calculated based on a general model that was performed using individual tree data. The total wood volume and wood biomass were larger at high planting density than at low planting density (Table 3). However, the wood volume per tree was smaller. The results support Cockerham (2004) and Wei et al. (2005) in which for commercial production, the high wood biomass is mainly obtained from intensive planting density.

Table 3. Average wood volume per planting density based on clear bole height and mean DBH.

Clone	Planting density	Mean DBH (cm)	Wood volume ($m^3 \cdot ha^{-1}$)
I	I	20.22	30.64
	II	19.19	101.70
	III	17.43	149.18
	IV	17.54	184.30
II	I	19.96	47.04
	II	16.29	66.91
	III	15.27	101.74
	IV	15.07	149.13

Discussion

We quantified the influence of planting density on some important growth attributes of rubber trees. Competition between trees was an effective determinant of tree growth. Statistically significant differences in nearly every measured attribute were found between the PD I and PD IV. Overall, all measured attributes were wholly affected by stand density.

DB-density relationship

Size-density relationships for *H. brasiliensis* plantations were similar to patterns reported for other species and regions. The relationship between mean DB and planting density tends to support this finding that spacing influences rate of plant growth (Bamber & Burley 1983). The different planting densities yielded a variety of diameters. This is strongly related to between-tree competition. In clone I, DB of PD I tends to be higher than that of other three planting densities. This demonstrated the negative effect of intra-specific competition. The analysis of intra-clonal differences showed a significant difference in mean DB between PD III and PD IV. In clone II, the mean DB of PD I was higher than for the other three planting densities. A significant difference in mean DB was detected between the PD I and the others. The present results fully support this finding that trees closely planted had slow growth rates, i.e., at high densities, the mean size is smaller and vice versa (Chadha 2001; Kerr 2003; Akram Nasir et al. 2006).

DBH-density relationship

In clones I and II, there were significant differences in mean DBH between PD I and PD III and PD IV (Table 1). The diameter was most affected by tree spacing as the largest diameter was recorded at the lowest planting density and the smallest diameter at the highest planting density (Scott et al. 1998; Cockerham 2004). Increased tree circumference is mainly related to growth ring width. Increasing the diameter of a tree, resulting tangential growth and anticlinal cells division, is required to continue with the increase in tree circumference (Lei et al. 1997). In wider spacing, plants will grow more and consequently produce larger stem girth. For commercial production, the most wood was produced at the highest planting density per hectare. Even though trees grown at the low planting density were larger and heavier, they were not large enough or heavy enough to exceed the total wood volume produced per hectare in the high density population.

BH-density relationship

BH was positively correlated with planting density. Maximum BH was recorded at PD III and PD IV for clones I and II (Table 1). The results are in accordance with the reference as the height is maximum in case of close plantation due to light competition and less space for expansion (Zobel & Van Buijtenen 1989; Akram Nasir et al. 2006). There is an indirect relationship between planting density and the total number of branches (Hein et al. 2008). Wider distance can make bole (epicormic) sprouting that leads to abundant branches and knots (Zobel & Van Buijtenen 1989; Chadha 2001).

For the quality and quantity of wood production, PD I showed the best growth performance in all the four planting densities (Table 1). The highest wood biomass was found in PD IV (Table 3).

PD I was chosen only for the purpose of comparison. This spacing was initially meant for more latex production but not for wood production, thus it will generate more branching and leaves, which is important for the production of latex. Since these clones were established and planted for higher wood production; the results from this study also indicated that higher planting densities resulted in more biomass production, which supports the

initial objectives of its establishment. As a result, the higher planting densities will give higher wood volume production at the shorter rotation time, and produces more wood for down-stream industries. Therefore, to realize a greater yield and weight, the focus should be on higher planting density.

Differences between wood qualities of different planting densities suggest that wood properties of plantation-grown trees in wider spacings are noticeably more valuable than lower spacings. These considerable differences were recognized in most anatomical and physic-mechanical properties (Naji et al. 2011).

Conclusion

The influence of four planting densities (500, 1,000, 1,500, and 2,000 trees·ha^{-1}) of clones RRIM 2020 and RRIM 2025 on some important tree attributes was studied in a trail rubber tree plantation in Malaysia. Different tree attributes such as DBA, DBH, and BH were notably affected by planting density.

Changes in the DB, DBH, and BH values forced by stand density caused significant reduction in the potential product of wood in widely spaced stands. DB and DBH of *H. brasiliensis* were greatest at PD I. BH in PD III and PD IV revealed positive relationship with the density of trees per hectare i.e. the most favorable planting density for commercial timber production is PD I. However, the most favorable planting density for biomass production is PD IV.

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